05191 Abstracts Collection
Graph Drawing
— Dagstuhl Seminar —

Michael Jünger[1], Stephen Kobourov[2] and Petra Mutzel[3]

[1] Univ. of Köln, DE
[2] Univ. of Arizona, US
kobourov@cs.arizona.edu
[3] Univ. of Dortmund, DE
petra.mutzel@cs.uni-dortmund.de

Abstract. From 08.05. to 13.05.05, the Dagstuhl Seminar 05191 "Graph Drawing" was held in the International Conference and Research Center (IBFI), Schloss Dagstuhl. During the seminar, several participants presented their current research, and ongoing work and open problems were discussed. Abstracts of the presentations given during the seminar as well as abstracts of seminar results and ideas are put together in this paper. The first section describes the seminar topics and goals in general. Links to extended abstracts or full papers are provided, if available.

Keywords. Graph Drawing, Visualization, Layout Algorithms, Interactive Visualization

05191 Executive Summary – Graph Drawing

This paper summarizes the topics, aims, and achievements of the Dagstuhl Seminar 05191 on Graph Drawing.

Keywords: Graph drawing

Joint work of: Jünger, Michael; Kobourov, Stephen; Mutzel, Petra

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/342

05191 – Open Problem Session Report

This is a report on an informal session intended to stimulate communication and sharing of problems. Hence the attributions and citations may contain inaccuracies, and are certainly not complete.

Keywords: Open problems, graph drawing

Joint work of: Whitesides, Sue

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/338

Matrix Zoom: A Visual Interface to Semi-external Graphs

James Abello (Rutgers Univ. - Piscataway, USA)

In web data, telecommunications traffic, and in epidemiological studies, dense subgraphs correspond to subsets of subjects (users, patients) that share a collection of attributes values (accessed web pages, email - calling patterns or disease diagnostic profiles). Visual and computational identification of these "clusters" becomes useful when domain experts desire to determine those factors of major importance in the formation of access and communication patterns or in the detection and contention of disease spread. With the current increase in available RAM and graphic hardware capabilities, it is more useful to relate graph sizes to the available screen real state S and the amount of available RAM M, instead of the number of edges or nodes in the graph. We offer a visual interface that is parameterized by M and S. It is particulary suited for navigation tasks that require the identification of subgraphs whose edge density is above certain threshold. This is achieved by providing a hierarchical zoomable matrix view of the underlying data. We illustrate the applicability of this work to the visual navigation of cancer incidence data and to aggregated samples of phone calls traffic.

Note: This work appears in the 2004 IEEE InfoVis Proceedings.

Keywords: Graph visualization, hierarchy trees, clustering, external memory algorithms, SEER cancer data, phone traffic

Joint work of: Abello, James; Van Ham, Frank

See also: James Abello, Frank van Ham. "Matrix Zoom: A Visual Interface to Semi-External Graphs," infovis, pp. 183-190, IEEE Symposium on Information Visualization (INFOVIS'04), 2004.

Setting up a Graph Drawing E-print Archive (GDEA) - a proposal

Michael Belling (Universität Köln, D)

E-prints are electronic copies of research output, like pre-prints, journal articles, conference papers, etc. An e-print archive is simply an online repository of such electronic copies. E-print archives promise many benefits for academics. They maximize visibility and accessibility of research. Based on these facts we propose the Graph Drawing E-Print Archive Project (GDEA).

Keywords: E-print archive, GDEA

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/340

Small visibility representations of SP-graphs

Therese Biedl (University of Waterloo, CDN)

In this talk, we consider how to draw a series-parallel graph. Like any planar graph, it can be drawn in $O(n^2)$ area in many drawing models. If we are not allowed to change the planar embedding, then this bound is tight.

As our main result, we show that if we are allowed to change the embedding, then all series-parallel graphs have a visibility representation (and hence also a polyline drawing) with area $O(n^{3/2})$. In many cases (in particular for outerplanar graphs and graphs of bounded maximum degree), the area requirement drops to $O(n \log n)$.

Keywords: Series-parallel graph, planar graph, visibility representation, polyline drawing

Crossings and Permutations

Franz J. Brandenburg (Universität Passau, D)

The rank aggregation problem finds a consensus ranking on a set of alternatives, based on preferences of individual voters. It is a well-established topic in social sciences, and has recently been applied to meta-search and spam reduction on the Web. Formally, there is a set of partial permutations representing the preferences of the voters and the objective is a total permutation at least cost.

We transform the rank aggregation problem into a crossing minimization problem for edge coloured graphs and investigate the sum and maximum number of crossings per colour. Our approach bridges the gap between rank aggregations and graph drawing and makes graph drawing techniques applicable to rank aggregation problems.

In particular, we establish the NP-hardness of the sum and the maximum number of crossings for just four permutations.

Keywords: Crossing minimization problems, permutations and 2-layer graphs, NP-hardness results

Joint work of: Biedl, Therese; Brandenburg, Franz J.

Highlighting Conflict Dynamics in Event Data

Ulrik Brandes (Universität Konstanz, D)

Continuing an idea that was born during Dagstuhl Seminar No. 01271 (Link Analysis and Visualization, 07/2001), a special session at the Sunbelt Social Networks Conference is devoted to the analysis and visualization of a large network data set by different research groups using different methods and perspectives. The session is known as the "Viszards Session" and consists of a joint presentation of the groups involved.

In this year's Viszards Session, the data consisted of political events in the Balkans from 1989-2003, coded by the Kansas Event Data System. In this talk I present our contribution to the session.

Joint work of: Brandes, Ulrik; Fleischer, Daniel; Lerner, Jürgen

Exact Crossing Minimization by Integer Programming

Christoph Buchheim (Universität Köln, D)

We present an exact approach for the crossing minimization problem using integer linear programming techniques. In our approach, the NP-complete problem of deciding realizability, which arises in the straightforward model, is avoided by replacing all edges of the graph by a path of (up to) $|E|$ edges. By this, we may assume that every edge crosses at most one other edge. This allows to characterize realizability by planarity of certain auxiliary graphs. We present an ILP modeling the crossing minimization problem in which the linear constraints prevent these auxiliary graphs from having any Kuratowski subdivision as subgraphs. Preliminary runtime results are reported. Moreover, it is shown that in terms of the solution quality the best known heuristic algorithms for crossing minimization are clearly outperformed by our exact approach, even on small and sparse instances.

Keywords: Crossing minimization, integer programming, planarization

Joint work of: Buchheim, Christoph; Ebner, Dietmar; Klau, Gunnar W.; Mutzel, Petra; Weiskircher, Rene

Non-Planar Orthogonal Drawings with Fixed Topology

Markus Chimani (Universität Dortmund, D)

We discuss the calculation of bend minimal shapes for non-planar graphs with given topology. Based on the Simple-Kandinsky drawing standard - a simplification of the more complex Kandinsky standard - we show the disadvantage of using standard models for this task: We show that the minimal bend count is suboptimal, when these models are applied to non-planar graphs; it is therefore beneficial to extend these standards. We define such an extension for Simple-Kandinsky called Skanpag (Simple-Kandinsky for Non-Planar Graphs). It treats edge crossings in a special way by letting them share identical grid points where appropriate. Hence it allows crossings of whole bundles of edges instead of single edges only. Besides having a reduced number of bends, drawings following this standard are easier to read and consume less area than those produced by the traditional approaches. In this paper, we show a sharp upper bound of the bend count, if the standard Simple-Kandinsky model is used to calculate shapes for non-planar graphs. Furthermore, we present an algorithm that computes provably bend-minimal drawings in the Skanpag standard.

The corresponding paper appeared at SofSem 2005.

Keywords: Bend minimization, non-planar, simple-kandinsky

Joint work of: Chimani, Markus; Klau, Gunnar W.; Weiskircher, Rene

Spine and Radial Drawings of Undirected Graphs

Walter Didimo (University of Perugia, I)

Among the wide set of graph drawing conventions, layered drawings have a long tradition; they require that the vertices of the graph are placed on geometric layers. Spine and radial drawings of undirected graphs are layered drawings such that the layers are parallel straight lines and concentric circles, respectively.

In this talk recent advances on crossing-free spine and radial drawings of graphs are presented within a common investigation framework, where the relationships between the number of layers and the number of bends are discussed. From this study, several intriguing theoretical and practical open problems arise.

Keywords: Spine drawings, radial drawings, layered drawings, planarity, bends

On Class Diagrams, Crossings and Metrics

Holger Eichelberger (Universität Würzburg, D)

As a standardized software engineering diagram, the UML class diagram provides various information on the static structure of views on software while design, implementation and maintenance phase. This talk gives an overview on drawing UML class diagrams in hierarchical fashion. Therefore, common elements of class diagrams are introduced and aesthetic rules for drawing UML class diagrams are given. These rules are based on four disciplines involved in the reading process of diagrams. After a brief introduction to our drawing algorithm, an extensive extension of the well-known Sugiyama algorithm, two details are highlighted: A new crossing reduction algorithm is presented and compared to existing ones and issues on measuring the quality of a layout are discussed.

Keywords: UML class diagrams, semantic aesthetic principles, hierarchical crossing reduction, layout metrics

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/339

Visualizing Multiple Related Graphs Simultaneously

Cesim Erten (University of Arizona, USA)

Although existing literature in graph drawing provides many useful pointers on drawing single individual graphs nicely, the problem generalized to finding simultaneous drawings of multiple related graphs has not received enough consideration. This generalization applies to two domains: Visualization of a single evolving graph or visualization of multiple graphs defined on the same set of nodes. Many applications that require a graph representation belong to one of the two domains. Yearly updated collaboration graph of a scientific research network or daily updated control-flow graph of a software project are examples of a single evolving graph. Biological pathways induced by different sets of enzymes, or pathways of similar cells from different organisms can be viewed as examples of multiple graphs defined on a similar set of nodes. Within the general framework of simultaneously drawing multiple related graphs there are two main directions. One direction restricts the class and the number of input graphs, and requires strict mental-map preservation between their layouts, whereas the other direction considers any number of general graphs relaxing the mental-map preservation conditions. We focus on the first direction and present polynomial time algorithms for several classes of planar graphs under the strict mental-map preservation conditions.

Topological Fisheye Views for Visualizing Large Graphs

Emden R. Gansner (AT&T Research - Florham Park, USA)

For graphs of up to hundreds of nodes and edges, there are many effective techniques available for visualization. At greater scale, data density and occlusion problems often negate its effectiveness. Conventional pan-and-zoom, and multiscale and distorted views are not fully satisfactory solutions.

As an alternative, we describe a topological zooming method. It is based on the precomputation of a hierarchy of coarsened graphs, which are combined on-the-fly into renderings with the level of detail dependent on the distance from one or more foci. We also discuss a related distortion method that allows our technique to achieve constant information density displays.

Keywords: Multiscale fisheye GUI, graph drawing, large data, topological zoom

Joint work of: Gansner, Emden R.; Koren, Yehuda; North, Stephen C.

Offline Drawing of Dynamic Graphs

Carsten Görg (Universität Saarbrücken, D)

In this talk, approaches to the problem of offline drawing dynamic graphs are presented: how to draw a given sequence of graphs which evolve over time by adding and/or deleting nodes and/or edges, such that the local quality of each drawing as well as the dynamic stability of all drawings is maximized. Unfortunately, these two goals conflict with each other in general.

To deal with the problem of conflicting optimization goals, new algorithms are developed which are parameterized such that they are able to trade stability for local quality and vice versa. Three different categories of graph drawing methods are investigated: force-directed, hierarchic, and orthogonal. All of these algorithms are integrated into a generic framework.

Metrics are used to check the stability of two successive drawings. So far, only metrics working on complete drawings of graphs have been known. Because the orthogonal and hierarchical algorithms use several phases, new metrics are introduced which work on intermediate results, that is on partial drawings of graphs and structures of drawings respectively.

The Fast Multipole Multilevel Method

Stefan Hachul (Universität Köln, D)

Given a large graph $G = (V, E)$ (containing several hundreds or thousands of nodes), several force-directed graph drawing algorithms exist that often generate a pleasing straight-line drawing of G in reasonable time. However, none of these methods guarantees a sub-quadratic running time in general. Furthermore, the quality of the drawings of "difficult" graphs like graphs that have a high edge density that contain many biconnected components or graphs that contain nodes with a very high degree is frequently improvable.

We developed a new force-directed graph-drawing method, called fast multipole multilevel method (or shorter FM^3) that is based on combining a multilevel strategy with a multipole-based tree-code for approximating the potential energy acting in a system of $|V|$ pairwise repelling charged particles. The running time of FM^3 is $O(|V| \log(|V|) + |E|)$ with linear memory requirements. In practice, FM^3 even visualizes clearly the structures of a big number of difficult graphs. The running times needed for drawing graphs containing up to 100.000 nodes are less than 5 minutes on a mid-range PC.

Keywords: Force-directed, large graphs, multipole method, multilevel method, fast algorithms, graph drawing

Joint work of: Hachul, Stefan; Jünger, Michael

Full Paper: http://kups.ub.uni-koeln.de/volltexte/2005/1409/

On Layering Directed Acyclic Graphs

Martin Harrigan (University of Limerick, IRL)

We consider the problem of layering a directed acyclic graph with minimum dummy nodes. We present a new Integer Linear Programming (ILP) formulation of the problem based on a set of fundamental cycles in the underlying undirected graph and show that it can be solved in polynomial time. We outline some of the advantages of the formulation. Each solution defines a family of layerings with the same number of dummy nodes. We can also transform one solution into another by adding or removing certain combinations of dummy nodes, thus allowing the consideration of other aesthetics.

Keywords: Graph drawing, hierarchical drawings, layerings, minimum dummy nodes

Joint work of: Harrigan, Martin; Healy, Patrick

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/343

Visualisation and analysis of large and complex networks

Seok-Hee Hong (The University of Sydney, AU)

Recent technological advances have led to many large and complex network models in many domains. Visualization can be an effective tool for analysis of such networks. Good visualisation reveals the hidden structure of the networks and amplifies human understanding, thus leading to new insights, new findings and possible prediction.

In this talk, we address these challenging issues for visualisation of large and complex networks and briefly introduce various new methods for visualisation of large and complex social networks and biological networks.

Two trees which are self-intersecting when drawn simultaneously

Michael Kaufmann (Universität Tübingen, D)

An actual topic in graph drawing is the question how to draw two edge sets on the same vertex set, the so-called simultaneous drawing of graphs. The goal is to simultaneously find a nice drawing for both of the sets. It has been found out that only restricted classes of planar graphs can be drawn simultaneously using straight lines and without crossings within the same edge set. In this paper, we negatively answer one of the most often posted open questions namely whether any two trees with the same vertex set can be drawn simultaneously crossing-free in a straight line way.

Keywords: Simultaneous graph drawing

Joint work of: Geyer, Markus; Kaufmann, Michael; Vrto, Imrich

Interactive Visualization of Graph Pyramids

Andreas Kerren (TU Kaiserslautern, D)

Hierarchies of plane graphs, called graph pyramids, can be used for collecting, storing and analyzing geographical information based on satellite images or other input data. The visualization of graph pyramids facilitates studies about their structure, such as their vertex distribution or height in relation of a specific input image. Thus, a researcher can debug algorithms and ask for statistical information. Furthermore, it improves the better understanding of geographical data, like landscape properties or thematical maps.

In this paper, we present an interactive 3D visualization tool that supports several coordinated views on graph pyramids, subpyramids, level graphs, thematical maps, etc. Additionally, some implementation details and application results are discussed.

Keywords: Graph pyramids, interactive visualization, exploration

Full Paper: http://drops.dagstuhl.de/opus/volltexte/2006/341

Visualizing Evolving Graphs by Simultaneous Embeddings

Stephen Kobourov (University of Arizona, USA)

Traditional problems in graph visualization involve the layout of a single graph, while problems in simultaneous graph visualization involve the layout of multiple related graphs. A series of related graphs may arise from one relation between a set of objects as it evolves through time or from several relationships defined on the same set of objects. In simultaneous embedding, nodes are placed in the exact same locations in all the graphs and a series of graphs is simultaneously embedable if it is possible to find node locations that yield straight-line crossing-free drawings for each of the individual graphs. We present polynomial time algorithms for simultaneous embedding of various classes of planar graphs and prove that some classes of graphs cannot be simultaneously embedded. Further, we present a near-linear time algorithm for visualizing graphs that evolve through time and demonstrate its application to problems in software engineering and databases.

Systems Biology: Networks Everywhere

Oliver Kohlbacher (Universität Tübingen, D)

Systems biology is a new integrative approach to biology. It requires a comprehensive analysis of large heterogeneous datasets of networks or biological data projected on these networks.

We discuss questions arising from the visualization and analysis of these networks and present BN++ and BiNA, two software packages for integrative analysis and visualization of systems biology data.

Keywords: Systems biology, BN++, omics, networks

Germany INC 1996 -2002: Capital Ties among the Top 100 German Companies

Lothar Krempel (MPI für Gesellschaftsforschung, D)

Internationalization and globalization are expected to change the way how national economic systems are organized. In this presentation I will explore how the German company system has changed between 1996 and 2002. The aim of this presentation is to highlight special features of the German company system, and record changes that occured. This becomes possible by applying spring algorithms to the data that describes capital ties among the largest 100 German companies over time.

Keywords: Capital networks, Germany, spring embedding, dynamic graph representations

Reachability Substitutes for Planar Digraphs

Martin Kutz (MPI für Informatik, D)

We investigate the reachability relations that a planar digraph induces on a subset of its nodes. Given a digraph $G = (V, E)$ with a set U of vertices marked "interesting", we want to find a smaller digraph $H = (V', E')$ with $V' \supseteq U$ in such a way that the reachabilities amongst those interesting vertices in G and H are the same. So with respect to the reachability relations within U, the digraph H is a substitute for G.

The complexity of finding such a reachability substitute of minimum size has so far been open. Besides showing NP-hardness of this problem, our main contribution is on planar digraphs: While almost all digraphs do not allow reachability substitutes smaller than $\Omega(|U|^2/\log|U|)$, every planar digraph has a reachability substitute of size $O(|U|\log^2|U|)$. Our proof rests on two new structural results for planar dags, a separation procedure and a reachability lemma. We believe that these parts are of independent interest and might be useful in the study of other, related problems.

Keywords: Reachability substitute, planar digraph, balanced cut, upward planarity

Joint work of: Katriel, Irit; Kutz, Martin; Skutella, Martin

An Algorithm for Finding Upward Planar Embeddings of Minimum Depth

Karol Lynch (University of Limerick, IRL)

The depth of an embedding is a measure of the nesting of its biconnected components or blocks. In this paper we present an algorithm for finding a fixed embedding of minimum depth amongst all upward planar embeddings of a digraph under the restriction that the embeddings of the biconnected components are fixed.

Keywords: Depth, upward planar embedding

Joint work of: Healy, Patrick; Lynch, Karol

A Space of Layout Styles for Clustered Graphs

Andreas Noack (BTU Cottbus, D)

Different inferences about clustered graphs impose different requirements on graph layouts that support these inferences. We derive requirements for graph layouts from various analysis questions, and classify the required layouts along three dimensions: layouts with meaningful distances between single nodes vs. layouts with meaningful distances between groups of nodes, layouts reflecting adjacency vs. layouts reflecting hierarchy, and layouts that faithfully reflect the size of subgraphs vs. layouts where certain subgraphs are magnified. We present a simple energy model for computing such layouts, and application examples from software analysis.

(Note: Paper appears in the Proceedings of the ACM Symposium on Software Visualization 2005)

Keywords: Graph drawing, force-directed methods, clustering, focus + context, clustered graphs

Joint work of: Noack, Andreas; Lewerentz, Claus

Complexity Results for Three-dimensional Orthogonal Graph Drawing

Maurizio Patrignani (Università di Roma III, I)

We introduce the 3SAT reduction framework which can be used to prove the NP-hardness of finding three-dimensional orthogonal drawings with specific constraints. We use it to show that finding a drawing of a maximum degree six graph whose edges have a fixed shape is NP-hard. Also, it is NP-hard finding a drawing of a graph with nodes at prescribed positions when a maximum of two bends per edge is allowed. We comment the impact of these results on the two open problems of determining whether a graph always admits a 3D orthogonal drawing with at most two bends per edge and of characterizing orthogonal shapes admitting a drawing without intersections.

Keywords: Three-dimensional graph drawing, orthogonal, NP-hardness

Graph Drawing Empirical Studies: Lessons learned

Helen Purchase (University of Glasgow, GB)

This talk will give a 'big picture' overview of our empirical studies of graph drawings, demonstrating the process of defining and working in a previously undefined empirical research area and the nature of incremental empirical studies. The form and the domain of the experiments will be described, and problems encountered and lessons learnt will be discussed.

Keywords: Experiments, empirical studies, graph drawing

Layout of Compound Hypergraphs with Orthogonal Hyperedges

Georg Sander (ILOG - Bad Homburg, D)

In [GD'2003, LNCS 2912, pp381ff, Georg Sander: Layout of Directed Hypergraphs with Orthogonal Hyperedges], we presented a technique to create a layout for flat directed hypergraphs as they occur in electrical diagramming and VLSI design.

In this talk, we extend this technique for compound hypergraphs, i.e. directed hypergraphs that have nodes that are hypergraphs. The main difficulty is to route the intergraph hyperedges, i.e., those hyperedges that go beyond the border of a single hypergraph.

Keywords: Graph layout, hypergraph, compound graph

Exploration of Biological Networks

Falk Schreiber (IPK Gatersleben, D)

Modern "omics"-technologies result in huge amounts of data about life processes. This data is often related to, or even structured in the form of biological networks such as protein-protein interaction, gene regulatory and metabolic networks. Visual data exploration methods help scientists to extract information out of the data and are very useful for building sophisticated research tools.

This presentation discusses examples of the analysis of biological networks and their user-friendly visualisation. These examples range widely from mapping and visualising experimental data in the context of the underlying biological networks to structural analysis and subsequent visualisation of biological networks based on motifs and centralities.

Visualizing Structural Properties of Irregular Parallel Computations

Martin Siebenhaller (Universität Tübingen, D)

An important task in parallel programming is the appropriate distribution of work on the processors. This distribution is usually dynamically changing and hard to predict, further it is very sensitive to the change of parameters. Even with advanced analysis tools this problem is hard to be solved. We propose to visualize the program structure as it changes over the execution time. We therefore present a new automatic layout algorithm based on Sugiyama's framework, which enables the user to detect structural patterns which might be fatal for the performance of the program - patterns which might be impossible to detect in a more analytical way. Furthermore it assists the user to find appropriate timing parameters for load balancing. We integrate our visualization into an integrated development environment that supports the implementation, execution, and analysis of parallel programs.

Keywords: Software visualization, parallel computing, visualization of parallel execution graphs, interactive performance tuning

Joint work of: Blochinger, Wolfgang; Kaufmann, Michael; Siebenhaller, Martin

Full Paper: http://doi.acm.org/10.1145/1056018.1056036

On the Chromatic Number of Some Geometric Hypergraphs

Shakhar Smorodinsky (Courant Institute - New York, USA)

A finite family IR of simple Jordan regions in the plane defines a hypergraph $H = H(IR)$ where the vertex set of H is IR and the hyperedges are all subsets $S \subset IR$ for which there is a point p such that $S = \{r \in IR \mid p \in r\}$. The chromatic number of $H(IR)$ is the minimum number of colors needed to color the members of IR such that no hyperedge of $H(IR)$ is monochromatic.

We study the chromatic number of hypergraphs that are defined by natural geometric instances such as discs, pseudo discs, axis-parallel rectangles etc. We obtain simple deterministic polynomial time algorithms for coloring such hypergraphs with "few" colors and show how to apply these results to obtain simple deterministic polynomial time algorithms for conflict-free coloring of such regions (where we want the property, that each point that is covered by the regions, is contained in at least one region whose color is unique, i.e., distinct from colors of other regions containing this point) with "few" colors.

Shape Matching for Curves and Graphs

Carola Wenk (Univ. of Texas at San Antonio, USA)

We present algorithms for comparing two curves, a curve with a graph, and two graphs. The distance measures we use are based on the Frechet distance, which is a distance measure that is well-suited for one-dimensional continuous objects.

Keywords: Matching, Frechet distance

Layout Problems in Nanotechnology: Changing the Scale

Sue Whitesides (McGill University - Montréal, CDN)

The graph drawing community has traditionally sought visualizations and layouts for graphs and networks that ease understanding of diagrams. Non-visual applications are typically to VLSI.

Here we give several examples to suggest the opportunities for interaction between the graph drawing community and researchers who are developing new small-scale fabrication techniques, from the nano to the micro scale. We also suggest that layout problems exist on a much larger scale, for example in the layout of networks of pipes.

Keywords: Micromanufacturing, nanotechnology, graph layout, graph drawing